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CLIMATE-SMART AGRONOMY FOR SMALL HOLDER COWPEA (*VIGNA UNGUICULATA* L. WALP) IN SOUTHERN NIGERIA

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ABSTRACT

Among smallholder farmers in Southern Nigeria, climatic variability is a major threat to the stability of cowpea (*Vigna unguiculata*) production, affecting yield, soil health, and livelihoods. This paper assessed the performance of identified climate-smart agronomic practices in increasing cowpea productivity, improving climate stress resilience, enhancing soil fertility, and improving socioeconomic performance. Four treatments, namely, conventional practice (control), mulching with an improved cowpea variety, intercropping with maize, and conservation tillage using compost, were replicated three times using a randomized complete block design. The grain yield was compared across three seasons, namely early season (normal rainfall), midseason (erratic rainfall), and late season (dry spell). The soil samples were tested to determine organic carbon, total nitrogen, moisture retention, and bulk density. Socioeconomic performance was measured by production costs, net income, and farmers' willingness to adopt. ANOVA at the 5% significance level was used to analyse the data, while LSD was used for mean separation. Findings revealed that cowpea performed well under climate-smart practices, with conservation tillage and compost, recording the highest average (1.25 t/ha), better soil health parameters, and a yield stability index (0.75). Mulching (72%) and intercropping (69%) were adopted willingly. The results indicate the potential to rely on climate-smart agronomic strategies to sustainably improve cowpea productivity, soil health, and farmers' livelihoods. Some of the recommendations include promoting these practices through training, access to inputs, extension, and climate information services.

***Keywords*:** Agronomic practices, Climate-smart agriculture, Cowpea, Smallholder farmers, Soil health.

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1. INTRODUCTION

Agriculture is an important sector for livelihoods, food security, and rural development in Nigeria, with smallholder farmers producing more than 80% of the country's agricultural output. Cowpea (*Vigna unguiculata*) is one of the food crops that is regarded as a valuable source of protein, adaptable, and useful as food, fodder, and soil supplement (Abebe & Alemayehu, 2022; Ikhajiagbe et al., 2024; Kim et al., 2025). Cowpea in Southern Nigeria is very important in terms of nutrition and earned income, particularly by resource-poor farmers (Ewansiha & Osaigbovo, 2017; Olasoji et al., 2023; Idohou et al., 2025). Nevertheless, climate change is progressively posing a threat to the production of cowpea in the form of increasing temperatures, unpredictable rainfall, long dry seasons, and occurrences of extreme weather conditions, which adversely affect crop development and yield stability (Ekhuemelo et al., 2020; Bolarinwa et al., 2021; Yeleliere et al., 2023). The challenges associated with climate change are especially high in sub-Saharan Africa, where the dominant agricultural systems are rain-fed and thus extremely susceptible to fluctuations in climate conditions. The trend in Southern Nigeria in recent years suggests that unpredictable rainfall, dry seasons, and heat stresses are encountered during the critical growth periods, resulting in poor crop establishment, low soil moisture, loss of nutrients and declining yields (Muleta & Gebremariam, 2023; Marcos-Garcia et al., 2024; Alawode, 2025). The production risk is also usually worsened by the fact that smallholder farmers do not have access to irrigation, climate information and better inputs (Bedeke, 2022; Olumide, 2024). The solution to such challenges is climate-smart agriculture (CSA) which aims to enhance productivity, resilience and environmental impact reduction (Effiong, 2024; Ukoh & Ikpe, 2025). A subset of CSA is climate-smart agronomy, which focuses on on-field management to promote good soil health, water-use efficiency, organic amendments, intercropping, and better varieties that help ensure yield stability during periods of

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climate stress. Mbanasor et al. (2024) affirmed that climate-smart practices have not been widely adopted by smallholder cowpeas farmers in Southern Nigeria in spite of their potential.

Healthy soils are vital in climate resiliency, where the deterioration of organic carbon, low nitrogen, high bulk density, and poor water retention are the general limitations (Lal, 2020; Blanchy et al., 2023; Maqbool et al., 2025). Agricultural techniques such as mulching, composting, and reduced tillage may enhance soil structure, water retention, and fertility, thereby cushioning crops against short-term climatic variations (Rivers et al., 2020; El-Beltagi et al., 2022; Al-Shammary et al., 2024). Constancy of yields and its sustainability in unfavorable situations is crucial to food security and income (Abdallah et al., 2021; Setsoafia & Renwick, 2022; Tabe-Ojong et al., 2023). However, there is limited empirical evidence of quantifying these benefits in the region.

The stability of yields during climate stress is also identified as one of the most important indicators of sustainable performance in agriculture. Although it is preferable to have an increase in yields, the fact that farming systems could offer fairly constant yields during drought and heat stress is significant to smallholder farmers who rely on regular harvests to obtain food and income (Snowdon et al., 2020; Omomowo & Babalola, 2021; Martey et al., 2021a; 2021b; Qiao et al., 2022). Climate-smart farming techniques would help minimize yield losses during unfavorable climatic conditions by enhancing root growth, conserving soil moisture, and improving microclimatic conditions within the crop canopy. Izuogu et al. (2025) hinted that there are few empirical studies of the benefits of cowpea in Southern Nigerian conditions.

Furthermore, Rasche et al. (2025) documented that adoption is also determined by socioeconomic factors like costs, earnings, labour, access to inputs, and perceptions. They noted that effective practices that are economically difficult and technologically demanding can be underutilized. Thus, a balance between agronomic and socioeconomic outcomes is key to the development of scalable interventions.

Due to the growing susceptibility of cowpea cultivation to climatic variability in Southern Nigeria and the paucity of empirical studies on integrated climate-smart agronomic interventions, there is a tangible necessity of developing research that objectively assesses these practices in terms of productivity, resilience, soil health, and socioeconomic characteristics (Mekonnen et al., 2022). The results of such a study can be used to give evidence-based recommendations to farmers, extension services, policymakers, and development practitioners who want to promote the use of climate-resilient and sustainable cowpea production systems.

The objective of the study was to assess how climate-smart agronomic activities influence cowpea productivity, soil health, stability of yield, and socioeconomic outcomes of smallholder farmers in Southern Nigeria. Comparing conventional practices with climate-smart practices, mulching with improved varieties and intercropping as well as conservation tillage with compost are some of the specific objectives that were used to determine sustainable, resilient, and acceptable practices.

1.1 The Conceptual Framework of Climate-smart Cowpea Agronomy

Climate-smart cowpea agronomy is a supplementary system that has been put in place to cushion the agricultural systems against climate stressors such as unpredictable rainfall and dry season spells. This practice improves both soil and crop physiology by using mulching, conservation tillage, and intercropping. Mulching and compost application enhance the water-holding capacity and organic matter of the soil, forming a moisture reservoir, which safeguards the crop during dry seasons (Martey et al., 2021a; Murga-Orrillo et al., 2023; Saber et al., 2024). Although conventional practices might suffer significant yield losses during dry outbreaks climate-wise, interventions such as conservation tillage and compost may make productivity more endearing and provide a greater systemic exemption.

This synergy as offered in Fig. 1 ultimately responds to four fundamental objectives, namely, productivity, resilience, soil health, and socioeconomic security. The combination of improved varieties and soil moisture preserving methods would also make sure that the yield is not affected by environmental pressures. This, to the farmer, means a crucial socioeconomic safety net; by reducing the risk of total crop failure and diversifying output through intercropping, it ensures not only an immediate food supply but also long-term stability in livelihood. This forms a vicious cycle where a sound soil base causes the system to continue being productive and a household that is increasingly secure because of the farming activity. Compost and mulching practices increased soil chemical and physical properties.

2. MATERIALS AND METHODS

2.1. Study Area

The research was carried out in smallholder cowpea communities in the humid rainforest and derived savannah agro-ecological zones of Southern Nigeria, which comprised Agbor and Asaba in Delta State and Uromi in Edo State (Fig. 2). Rainfall displayed a bimodal pattern in regions characterized by increasing rainfall variability, recording annual totals of 1,500–2,500 mm, and temperatures oscillating from 26 to 32°C. The climatic problems in these

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areas include unpredictable rainfall, dry spells, and increased temperatures that impact the production of cowpea.

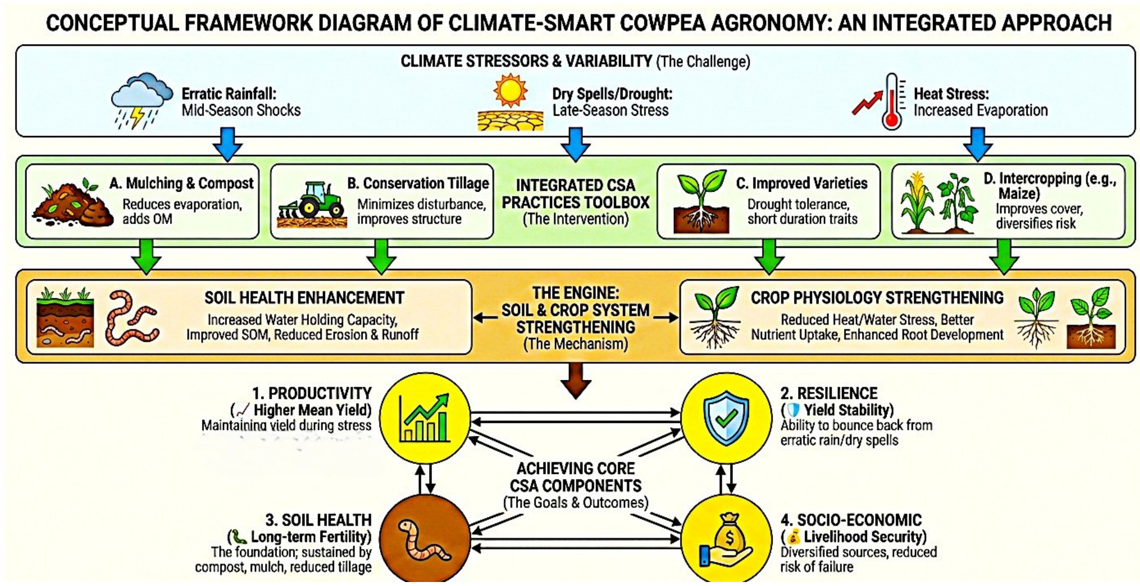

Fig. 1: Conceptual framework of climate-smart cowpea agronomy.

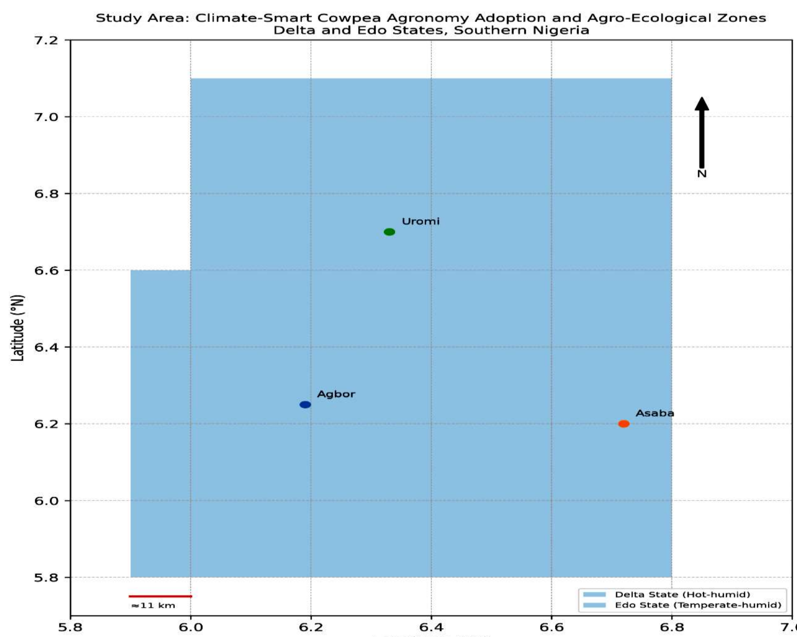

Fig. 2: Study Area with locations.

2.2. Experimental Design and Agronomic Treatments

In this study, a randomized complete block design (RCBD) was adopted with 4 treatments and 3 replications. Cowpea planting materials were obtained from the International Institute for Tropical Agriculture, (IITA) Ibadan. The treatments were (1) conventional practices, which incorporated farmer-managed tillage, the local variety of cowpea, and no soil improvements; (2) mulching with an improved cowpea variety, where organic mulch (dry grass at 5 tons per hectare) was applied after planting; (3) intercropping between cowpea and maize at a row ratio of 1:1; and (4) conservation tillage using compost, which involved minimum tillage of the soil and the application of 4 tons per hectare of well-decomposed compost before planting. All the plots measured 5 x 5 m and 75 by 20 cm of planting space. All practices were implemented according to standard agronomic protocols suitable for the region, and treatments were applied throughout the growing periods.

2.3. Seasonal Climate Scenarios

To measure climate variability, the cropping season was divided into three seasons based on rainfall patterns: the early season, with normal rainfall; the midseason, with erratic rainfall; and the late season, with a dry period. The crop's yield responses to these specific climatic conditions were interpreted using rainfall and temperature data obtained from local meteorological stations.

2.4. Yield Data and Yield Stability Data Collection

2.4.1. Crop Yield Measurement: The yield of cowpea grains was indicated in tonnes per hectare (t/ha) at harvest under the three seasonal conditions known as early (normal rainfall), erratic rainfall, and dry spell. The average yield of each treatment was determined in the seasons.

Yield Stability Index: Yield stability index was estimated through the percent yield losses under climatic stress (drought and heat) as compared to that of optimum conditions, and the index was then obtained.

2.4.2. Soil Sampling and Analysis: Before planting and harvesting, composite soil samples (0-20 cm deep) were taken. Organic carbon of the soil was determined by the Walkley-Black method; total nitrogen by the Kjeldahl digestion method; moisture retention by the gravimetric method after saturation and drainage; and bulk density by the core sampling method. These measurements were applied to evaluate the impacts of climate-smart agronomic practices on soil health.

2.4.3. Economic Analysis: Each practice was tabulated on the cost of production, gross income, and the net farm income. The survey on farmer willingness to adopt practices was conducted by structured interviews, and the responses were expressed in percentages.

2.5. Data Analysis

The data were processed using descriptive statistics and ANOVA with a 5% level of significance. Mean separation was carried out using LSD, in which there were significant differences. ANOVA expectations were also tested, and the significance was indicated at P ≤ 0.05. Findings were contained in figures and a table, which were used to express how climate-smart agronomic practices affected cowpea yield, soil health, yield stability, and socioeconomic performance.

Analysis of Variance (ANOVA) was performed to assess the treatment effect on cowpea yield and soil health indicators. The ANOVA was done using the following model:

$$Y_{ij} = \mu + \tau_i + \rho_j + \epsilon_{ij}$$

where Y_{ij} is the response variable, μ is the grand mean, τ_i is the effect of the treatment, ρ_j is the effect of the replication, and ϵ_{ij} is the error term.

The F-test was used to determine the significance of treatment effects at the 5% level. When significant differences were identified, the Least Significant Difference (LSD) test at P ≤ 0.05 was employed for mean separation. All statistical analyses were performed using SPSS.

3. RESULTS AND DISCUSSION

The results of the study are presented in Fig. 3 to 6 and Table 1. Fig. 3 shows the response of cowpea grain yield to varying climatic-smart agronomic practices under varying patterns of rainfall during the seasons. The figure clearly shows that cowpea yield decreased from the early season with normal rainfall to the late season with dry spells across all treatments, reflecting the strong effect of rainfall variability on yield. In the conventional method (control), grain yield was continuously lowest in the early season, ranging from 0.85 t/ha to 0.41 t/ha in the late season with an average yield of 0.63 t/ha. This drastic reduction suggests that the conventional practices are very susceptible to unpredictable and lower rainfall patterns. Ojo et al. (2021) documented that rainfall variability directly impacts water availability, which in turn influences cowpea yield and productivity, as shown in regions like Southwestern Nigeria and semi-arid Brazil, where drought periods caused notable yield declines.

Conversely, climate-smart agronomic activities led to a significant enhancement in yield stability and overall productivity, consistent with the findings of Samim et al. (2024). The yield attained by mulching with improved variety was high in all seasons: 1.45 t/ha in the early season, 1.18 t/ha in the mid-season with erratic rainfalls, and 0.96 t/ha in the late-season dry spells, which gave an average yield of 1.20 t/ha. Similarly, cowpea intercropping with maize increased yield performance over the control, with values of 1.32, 1.05, and 0.88 t/ha in the early, mid, and late seasons, respectively, and a mean of 1.08 t/ha. The conservation tillage with compost application recorded the highest and most constant yields with 1.50 t/ha in the early season, 1.22 t/ha in the mid-season, and 1.02 t/ha in the late season which showed the highest means yield of 1.25 t/ha. This result is supported by the reports of Sajjad (2021) who noted that conservation practices such as mulching and soil cover can help maintain soil moisture and

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mitigate water stress effects on cowpea yield during dry spells.

In a broad sense, Fig. 3 shows that climate-smart agricultural activities can reduce negative impacts of unpredictable rainfall patterns and drought by enhancing soil moisture storage, nutrient supply, and crop resistance, maintenance of cowpea high yields in varying seasonal patterns compared to conventional application means.

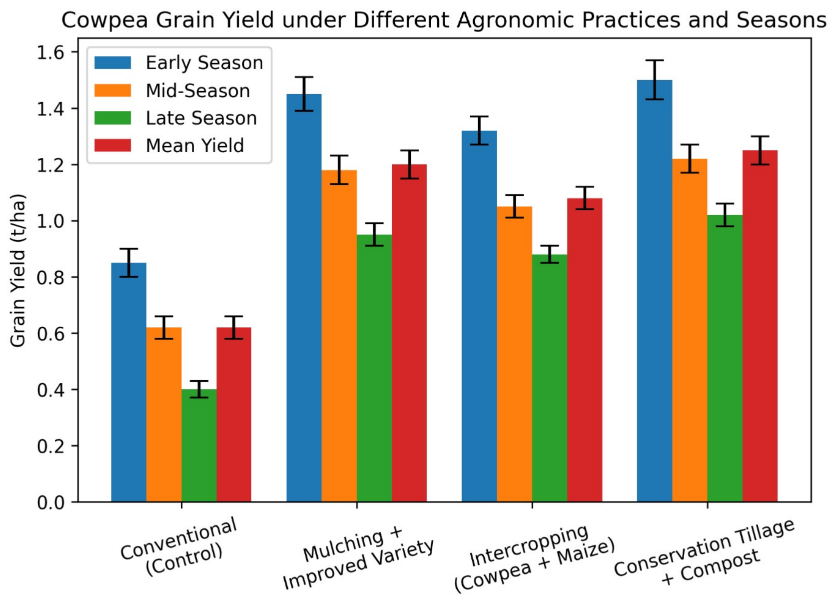

Fig. 3: Effect of Climate-smart Agronomic Practices on Cowpea Grain Yield (t/ha).

The relative impact of climate-smart and conventional agronomic practices on the main indicators of soil health is shown in Fig. 4. The findings indicate that the system of climate-smart practices remarkably enhanced the quality of soil as compared to the conventional system. The organic carbon in the soil rose from 0.92 to 1.62% between the conventional management and the climate-smart management, suggesting the increase of the organic matter buildup in the soil and the rise in soil fertility. Equally, total compost plus nitrogen also increased from 0.07% in the conventional plots to 0.14% in climate-smart practices, which was an indication of improved nutrient enrichment and possible continued crop productivity. There was also a significant increase in soil moisture retention, with climate-smart practices increasing to 57.9% from the 38.4% of the conventional system, which underscores the importance of better soil cover and organic inputs in preserving soil water. Conversely, bulk density dropped to 1.28 g cm^{-3} in climate-smart plots compared to 1.56 g cm^{-3} in conventional practice, which showed an index of reduced soil compaction and enhanced soil structure. Affirmations to these results were documented by Jat et al. (2020), Tadesse et al. (2021) and Kichamu-Wachira et al. (2021).

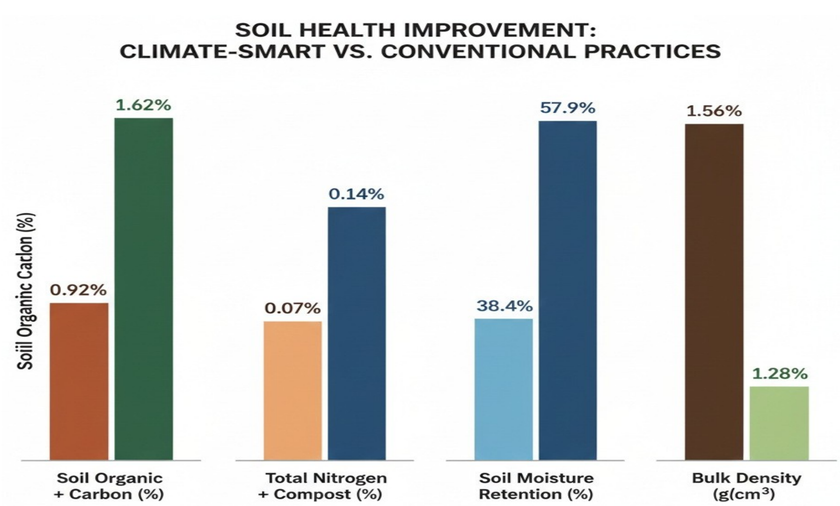

Fig. 4: Soil Health Improvement: Climate-smart Vs Conventional Practice

Colour Legends:

- Orange/Brown Bars: Represent conventional (Before) practices.
- Dark Green, Dark Blue, Light Green Bars: Represent Conservation + Compost (After) practices.

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On the whole, the figure shows that climate-smart farming methods increased the soil fertility, water storage and physical state, thus, providing a more favourable soil environment to sustain cowpea production.

Fig. 5 represents the stability index of cowpea yield under climatic stress factors, especially drought and heat stress. The largest decrease in yield was recorded in conventional practice, comprising 52.0% under drought stress and 48.3% under heat stress, which led to a low yield stability index of 0.42. Conversely, conservation tillage with compost proved to be most stable with the least yield losses of 24.6% during drought and 22.1% during heat stress, with a better yield stability index of 0.75, similar to the reports of Bilibio et al. (2023) and Dugan et al. (2024). Mulching with an improved variety and intercropping systems also improved stability compared to conventional methods, with yield reductions of 28.5% and 31.2% under drought and 25.7% and 29.4% under heat stress, respectively, also support the documentation of Ahmad et al. (2022) and Bezboruah et al. (2024). On the whole, conservation tillage with compost was the most resilient to climate stress, as it ensured greater yield stability of cowpea under unfavourable environments.

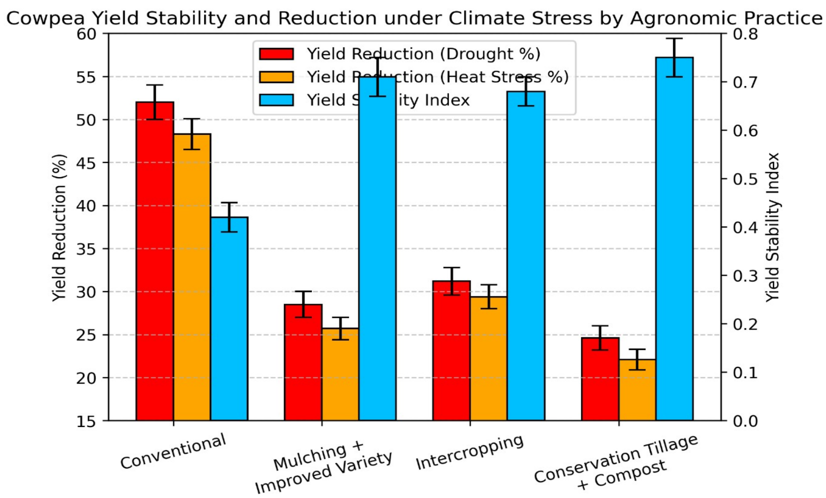

Fig. 5: Yield Stability under Climate Stress.

Fig. 6 emphasizes the socio-economic performance of the different climate-smart cowpea agronomic practices with production cost, income, profitability, and willingness of farmers to adopt. The conventional practice has the lowest unit of production at 145,000 per hectare; however, it has the lowest gross income (210,000) and net farm income (65,000). Conversely, conservation tillage with compost was the most expensive (₦175,000) and at the same time yielded the greatest gross income (₦370,000) and net income (₦195,000), which reflects good profitability. In spite of these economic advantages, the adoption of conservation tillage and compost by the farmers was very minimal at 7%. On the other hand, there are lower profitability practices like mulching, using better varieties, and intercropping, which are cheaper but have higher rates of adoption of 72 and 69, respectively. In general, as opposed to the acceptability of practices like mulching and intercropping by farmers, conservation tillage using compost has had the highest economic payoffs, but other factors like cost or other obstacles appear to curtail the encouragement of the practice, in agreement with the findings of Martey et al. (2021b).

Table 1 shows the analysis of variance (ANOVA) of the impact of climate-smart agronomic practices on the cowpea grain yield (t/ha). The findings demonstrate that the agronomic practices can significantly influence the cowpea grain yield, as the F value of 18.72 and the P value of 0.001 were extremely low, even lower than the 0.05 level of significance. This means that differences in the yield of the grains observed in the agronomic practices as compared to the agronomic practices that were tested did not occur randomly but were highly dependent on the form of management practice used. The sum of squares (SS = 1.842) and the mean square (MS = 0.614) were also relatively high, which further indicates that this source of variation explained a significant percentage of the overall variability in cowpea yield, which is a reflection of the effectiveness of climate-smart interventions in improving productivity.

Conversely, the outcome of replications did not show significant difference, as the F value was 1.31 and the P value was 0.314. This implies that there were no significant differences between replications that would have impacted the cowpea grain yield, and, therefore, the experimental conditions were fairly consistent across replications and the treatment effects were consistently manifested. The error term had a low mean square value of 0.033, which represents low unexplained variation, implying that there is good experimental precision and reliability of the data.

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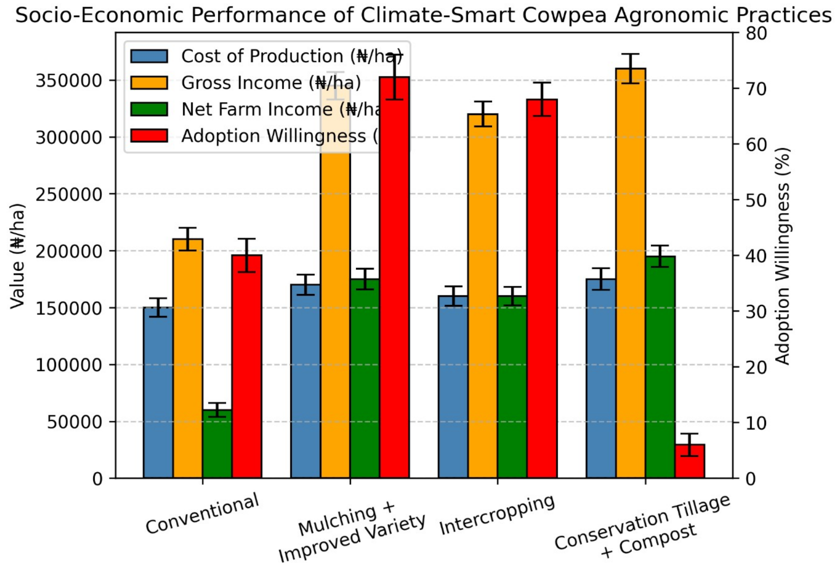

Fig. 6: Socio-Economic Performance of Climate-smart Cowpea Agronomic Practices.

Table 1: Analysis of Variance (ANOVA) for Effects of Climate-smart Agronomic Practices on Cowpea Grain Yield (t/ha)

Source of Variation	Degrees of Freedom (df)	Sum of Squares (SS)	Mean Square (MS)	F value	P value
Agronomic Practices	3	1.842	0.614	18.72	0.001
Replications	2	0.086	0.043	1.31	0.314 ns
Error	6	0.197	0.033	–	–
Total	11	2.125	–	–	–

Significance level: P≤0.05; ns = not significant, s = significant at 1%.

In general, the ANOVA findings validate the assumption that climate-smart agronomic methods enhanced cowpea grain yield significantly (p=1 percent) and random experimental error and replication effects had little impact.

The research results demonstrate that climate-sensitive agronomic strategies significantly outperform traditional farming methods in enhancing cowpea crop production, improving soil quality, stabilizing yields, and responding socioeconomically to climate variability in Southern Nigeria. These conclusions align with a broader body of literature suggesting that field-level adaptive management can mitigate the effects of climate change on smallholder agricultural systems in sub-Saharan Africa and other regions (Bedeke, 2022; Okoronkwo et al., 2024; Alawode, 2025; Singh et al., 2025).

The high yield of grain under conservation tillage using compost (1.25 t/ha average over seasons) compared to the control (0.63 t/ha) is consistent with the results of similar literature in humid and sub-humid tropical settings. According to Tadesse et al. (2021), climate-smart agricultural practices in the southern region of Ethiopia have effectively raised soil carbon stocks and enhanced crop production. According to Li et al. (2025) the use of organic amendments, particularly compost, is crucial as it improves the cation exchange capacity, biological activity, and availability of soil nutrients, which enhances crop nutrition throughout the growing cycle. Additionally, the role of organic carbon in increasing the soil's water-holding capacity accounts for the relatively high yields observed in conservation tillage plots, even during the late-season dry periods when conventional farming methods see significant yield declines. Such biophysical processes are extensively recorded in the literature about soil-water-plant interactions in the tropical setting (Geris, 2020; Jat et al., 2020; Kühnhammer et al., 2023; Al-Shammary et al., 2024).

The observed mechanical expansion by the continued improvement of the soil health parameters in climate-smart plots such as, higher organic carbon (0.92% to 1.62%), total nitrogen (0.07% to 0.14%), and moisture retention (38.4% to 57.9%) and decreased bulk density (1.56 to 1.28 g cm-3) offers a mechanistic justification of the yield differences that were found in treatment. In a meta-analysis of climate-smart practices of agricultural activities in Africa, Kichamu-Wachira et al. (2021) identified similar increases in soil carbon and nitrogen in reduced tillage and organic input systems, with moisture retention as one of the most important non-random determinations of yield within unpredictable rainfall. The decrease in bulk density in this study indicates improved macro porosity and aeration of the soil, which promote deeper root penetration and enhanced access to groundwater during dry spells. This is especially urgent regarding cowpea (*Vigna unguiculata*) because nodulation and nitrogen fixation are highly sensitive to soil physical attributes (Omomowo & Babalola, 2021; Ikhajiagbe et al., 2024). The mulching processing, which also conserved the moisture of the soil by minimizing the surface evaporation, also improved the soil conditions which were also supported by the works of El-Beltagi et al. (2022) who reported that, in semi-arid and sub-humid tropical systems, the mulching process significantly increased the water retention of soil, temperature, and organic matter.

The treatments evaluated can be categorized by yield stability, which was assessed through performance across three seasonal rainfall regimes and formal stress indices. Soil-improving practices, notably conservation tillage combined with compost, show a yield stability index of 0.75, outperforming the conventional practice index of 0.42. In Southern Nigeria, smallholder farmers depend on the predictability of their harvests for food security and income generation (Ewansiha & Osaigbovo, 2017; Bolarinwa et al., 2021).

Practices that minimize season-to-season yield variability were economically valuable, as highlighted by studies demonstrating the benefits of conservation tillage and soil conservation methods in drought conditions. Ling et al. (2025) observed that such practices enhance soil multifunctionality and microbial network complexity, while Sajjad (2021) noted that water shortage stress impacts legume productivity, particularly cowpea, suggesting that mulching and reduced tillage can improve soil moisture distribution. Furthermore, intercropping cowpea with maize yielded a mean of 1.08 t/ha and exhibited lower yield losses during drought (31.2%) and heat stress (29.4%). The advantages of intercropping stem from efficient resource utilization—light interception and nitrogen transfer between crops, along with maize's microclimate buffering. This aligns with findings from Ojo et al. (2021), indicating that legumes in cereal-based intercropping systems improve productivity and resource efficiency under variable rainfall conditions. Intercropping also diversifies agricultural production, serving as a financial safety net in low-yield years; the socioeconomic analysis indicated a 69% farmer willingness-to-adopt rate, marking it a viable climate-smart strategy for resource-constrained smallholders.

The research reveals a complex relationship between agronomic performance and adoption behavior in farming practices. Conservation tillage yielded the highest net farm income (N195,000/ha) but had a low adoption rate of 7%. This suggests that significant structural barriers, such as labor-intensive compost preparation, limited access to inputs, and insufficient technical expertise, impede the uptake of this practice. Similar limitations were identified by Mbanasor et al. (2024), who noted that smallholder farmers in Southeast Nigeria cited technical complexity and lack of inputs as common obstacles to the adoption of climate-smart agriculture. Rasche et al. (2025) emphasized that perceived complexity and resource demands of practices like inoculation and organic amendments deter adoption, despite their agronomic benefits. In contrast, more straightforward practices like mulching (72% adoption) and intercropping (69% adoption) demonstrated higher acceptance among farmers. This underscores the importance of integrating both practice acceptability and agronomic effectiveness in designing scalable climate-smart interventions, as supported by the findings of Martey et al. (2021a; 2021b).

The implementation of conservation tillage using compost was limited, raising concerns regarding the role of extension services and farmer training. Ayalew and Yoseph (2022) noted that climate-smart cowpea methods, integrated into structured farmer education programs, significantly improve adoption rates and productivity by boosting farmer confidence and simplifying new practices. Izuogu et al. (2025) echoed this, stating that climate-smart initiatives in Nigeria's smallholder environments require institutional backing, including climate advisory services and community demonstration plots. They argue for a shift in extension systems from mere technology transfer to a co-learning and adaptive management platform that addresses farmers' immediate needs. The theoretical framework supporting the study positions climate-smart agronomy as a means to enhance productivity, resilience, soil health, and socioeconomic security, validated by empirical data. The findings indicate there is no single best practice across all four dimensions; rather, a combination of conservation tillage, composting, mulching, and intercropping offers the most effective approach for smallholder cowpea systems in Southern Nigeria. This integrative viewpoint aligns with the climate-smart agriculture vision endorsed by the Food and Agriculture Organization and affirmed by regional scholars (Mbanasor et al., 2024; Alawode, 2025; Izuogu et al., 2025).

In the context of climate variability in Southern Nigeria, findings indicate that areas in Delta and Edo States are increasingly affected by unpredictable rainfall patterns, with more frequent dry spells and shorter effective growing periods (Bedeke, 2022; Alawode, 2025). This situation enhances the advantage of climate-smart practices over traditional farming, prompting a need for greater support in promoting these methods. Bolarinwa et al. (2021) cautioned that without enabling policy environments, recommendations for rural credit schemes and input subsidies will not result in significant behavioral changes. The paper advocates for the integration of agronomic interventions into large-scale agricultural development programs that address the various limitations faced by smallholders. Ultimately, it confirms that climate-sensitive agronomic systems are viable for sustainable cowpea cultivation, with compost conservation tillage offering substantial agronomic and economic benefits. Additionally, practices such as mulching with improved varieties and cowpea-maize intercropping are deemed implementable resilience strategies.

Effective scaling of these solutions will require coordinated efforts among extension services, policymakers, and development partners to improve access to inputs, provide necessary training, and create supportive conditions for sustained adoption.

3.1. Integration of Findings

Generally, the research demonstrated that the main goals of climate-smart agronomic practices include the aspects of productivity increase, resilience, soil health maintenance, and social economic gain. Conservation tillage with compost had the best yields, soil enhancement, and stability, whereas mulching with superior varieties was a compromise between crop production and a high level of adoption. Intercropping provided moderate benefits but was still higher than conventional practice across all measured parameters. These results are in line with the conceptual framework of climate-smart agriculture that focuses on the simultaneous realization of productivity, adaptation, and sustainability objectives.

The study also outlines the significance of situating climate-smart interventions within the realities of smallholder farming. Some of the practices will face barriers to adoption due to labour, input accessibility, or technical expertise, despite being technically superior. Thus, it is necessary to incorporate socioeconomic factors and agronomic efficacy to scale climate-smart practices and produce substantial changes in Southern Nigeria.

4. CONCLUSION

The discussion establishes that climate-smart agronomy can provide a feasible channel for enhancing the productivity of cowpea, soil health, and resilience to climate stress and also provide economic gains to smallholder farmers. The results are in line with the purpose of the study and offer practical information to extension services, policymakers, and development programs that are intending on encouraging the cowpea production systems that are sustainable and climate resilient in Southern Nigeria.

In order to maximally harness the advantages of climate-smart activities by smallholder farmers, it is vital to use extension services, demonstrations, and farmer field schools to ensure that people gain practical knowledge and practical experience. Specific training needs should be established to increase the skills of farmers in preparing compost, mulching, and intercropping processes, which will boost their confidence and ability to use them. Accessibility of better cowpea varieties, organic manure, and mulching products should also be improved to ensure that most people adopt it. Also, it is possible to come up with incentives like subsidies and microcredit programs to motivate farmers to use labour- and resource-intensive methods that will have long-term payoffs. The use of climate information services in the farming activities can aid the farmers in maximizing the planting dates and dealing better with the stresses. Lastly, the climate-smart agronomic practices that are being integrated into the national policies and development programs will play a crucial role in scaling the practices in a sustainable manner and guaranteeing the long-term effect of the practices on resilience and productivity.

Declarations

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Data Availability: Data will be made available upon request.

Ethics Statement: Only cowpea (*Vigna unguiculata*) plants were involved in the study. No aspect of it involved human or animal samples therefore no ethical approval was required.

Author's Contributions: Anthony O. Ukpene conceived and designed the study, coordinated the field experiments, data analysis and drafting of the manuscript. Collins O. Molua helped with the design and analysis of experiments and the interpretation of results, especially regarding yield stability and climate variability. Thelma E. Konyeme was involved in field data collection, soil sampling, laboratory analysis, and the materials and methods. Belonwu E. Eunice did the socioeconomic survey, analyzed the adoption and economic data, and participated in the discussion of socioeconomic outcomes. John C. Morka aided data management, helped with statistical modeling, and helped in the review and technical editing of the manuscript.

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